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THERMAL CONDUCTIVITY OF STRIPA DRILL CORE ROCKS

by

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ABSTRACT

Thermal conductivity of rock specimens from four drill core sections from the Stripa mine in Sweden was measured in the temperature range of 40° to 500°C. Cylindrical specimens were prepared parallel to the axis of the drill cores with the exception of drill core E13 (7.5). In this case pronounced mylonite shears and fractures were visible and the cylindrical specimens were cut in different directions so as to include these structural irregularities.

The thermal conductivities of the Stripa rocks were found to be similar except for the specimen with the mylonite shears, in which case the results were approximately 10% higher. The thermal conductivities of the Stripa rocks are highly temperature dependent. This characteristic could cause relatively steep thermal gradients and would contribute to thermal instability of the rock mass.

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CONDUCTIVITÉ THERMIQUE DES ROCHES PROVENANT DES CAROTTES DE FORAGE DE STRIPA

par

V.V. Mirkovich*

RÉSUMÉ

On a mesuré, dans quartre sections de carottes de forage provenant de la mine de Stripa en Suède, la conductivité thermique d'échantillons de roches, dans une gamme de températures comprise entre 40° et 500°C. On a préparé des éprouvettes cylindriques et parallèles à l'axe des carottes de forage, à l'exception de la carotte E13 (7.5). Dans ce cas, il s'agissait d'une mylonite dans laquelle les fractures et cisaillements étaient visibles, et dont on a coupé les éprouvettes cylindriques dans diverses directions, de façon à inclure ces irrégularités.

On a constaté que la conductivité thermique des roches de la mine de Stripa ne variait pas, excepté dans l'échantillon de mylonite caractérisé par des cisaillements, pour lequel on a obtenu des valeurs d'environ 10% supérieures. La conducitivité thermique des roches de Stripa dépend fortement de la température. Cette caractéristique pourrait donner lieu à des gradients thermiques relativement élevés, et provoquer l'instabilité thermique de la masse rochesuse.

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INTRODUCTION

Depending on the nature of irradiated nuclear fuel, the heat generation due to radioactive decay may continue for decades and even centuries. In the case of a rock repository, particular consideration should be given to the effect of heat on the confining walls of the cavity. Thermal conductivity is an important thermophysical parameter because it establishes the rate at which heat from the radioactive waste would be dissipated through the rock mass. Its absolute value and the rate of change of this value with temperature provides a sensitive measure for evaluating the loading capacity of a repository and the thermal stability of the surrounding rock masses.

This study, made at the request of Lawrence Berkeley Laboratory, University of California (1), is a contribution to international cooperation on research into radioactive nuclear waste disposal. The rock specimens originate from the Stripa mine in Sweden, where in situ thermal tests have been performed to test the stability of the rock mass.

Because of the complex nature of rocks and their wide variations in texture and composition, it is impossible to predict with any degree of accuracy their thermophysical properties. It is particularly difficult to foresee what changes can occur in thermal transport properties in structural and fractural rocks. To determine the thermal behaviour of the rock mass at Stripa mine, the thermal conductivity of rock specimens obtained from several levels of the Stripa drill core was measured in unconstrained conditions in the temperature range of approximately 40° to 500°C.

PROCEDURES

METHOD OF MEASUREMENT

The thermal conductivity measurements were made in a modified comparative-method thermal conductivity apparatus, the original version of which was described previously (2). The modification consists of a provision for cooling the heat sink and the heat guard. This modification allows measurements to be made at temperatures as low as 30°C. In essence, a 2.54 cm diameter rock specimen, 2.54 cm high, is placed between two standards of the same dimensions. The three cylinders are placed on a cylindrical heat stabilizer, also of the same dimensions. The column

consisting of four cylinders is held between the heat source and heat sink with the heat stabilizer placed next to the heat source. The entire assembly is surrounded by a cylindrical heat guard. By adjusting the power input to the guard heaters wound on the outside of the heat guard, heat flow can be constrained to the axial direction only. Under such conditions the temperature gradients in the cylinders will be inversely proportional to thermal conductivity. As the conductivity of the standards is known, the thermal conductivty of the specimen can be readily calculated.

The measurements were made in the 40°-500°C temperature range. Temperatures were measured with 28 B&S gauge chromel-alumel thermocouples. Pyroceram Code 9606* was used for the standards and the heat stabilizer. All measurements were made at successively increasing temperatures. The temperature gradients within the rock samples were approximately 20°C. The accuracy of the measurements is estimated to be ±5%.

MATERIALS

The rocks for this study were obtained from extensiometer holes drilled in full-scale and extensiometer drifts in the Stripa mine. The exact position of the bore holes is discussed by Kurfurst et al (3). Four drill core segments were selected by Lawrence Berkeley Laboratory from the following drill cores: E29, E14 and E13. The sample E29 was located 3.15 m into the bore hole. The position of the sample E14 was at 8.9 m. Two samples were taken from the bore hole E13, one at 7.5 m, and the other at 9.0 m. For purposes of differentiation, specimens E13 are referred to as E13(7.5) and E13(9.0).

General characterization of the Stripa rocks was made by Wollenberg et al. (4) who classified them as quartz monzonite. The results of the petrographic analysis by Soles (5) of the drill core specimens E29, E14, E13(9.0) and E13(7.5) are given in Table 1. The position and approximate orientation of the petrographic specimens are shown in Figure 1. Because of pronounced mylonite shears and chlorite filled fractures, two petrographic specimens were taken from drill core E13(7.5). Specimen E13(7.5)-A was cut so as to include the mylonite shears, whereas specimen

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*Pyroceram Code 9606 is a polycrystalline glass-ceramic made by Corning Glass Works, Corning, New York.

E13(7.5)-B contained only the small and random fractures. As it can be seen from Table 1, there is an appreciable composition difference between the two petrographic specimens.

The segments of the drill cores E29, E14 and E13(9.0) contained only random and relatively small fractures. Only one petrographic specimen was taken from each of these segments.

Because of shears and fractures in the sample E13(7.5), specimens for measurement of thermal conductivity have been cut in specific locations and orientations. As shown in Figure 1, specimen C1 was cut so that the mylonite shear of the core would be parallel to the principal axis of the cylindrical specimen. On the other hand, the orientation of the C2 specimen was such that the chloritic fractures were approximately perpendicular to the axis of the cylinder. Specimen C3 was prepared from the portion of the core that had essentially no visible fractures. In the case of samples E29, E14 and E13(9.0), the cylindrical specimens were cut with their axis parallel to the axis of the core.

The specimens were prepared in the form of 2.54 cm diameter, 2.54 cm high cylinders. They were ground to a tolerance of ±0.0025 cm with the ends lapped plane and parallel. Each cylinder was provided with two 0.75 mm diameter thermocouple holes, which were drilled radially 12.5 mm deep from the surface to the cylinder's axis at a distance of 1.65 mm from each end.

RESULTS AND DISCUSSION

The results of the thermal conductivity measurements are shown in Figures 2 and 3. The curves were fitted to the data by the least squares method. Each curve represents 9 to 14 conductivity measurements. The curves are also expressed by the equation:

$$\lambda = a_1 + a_2 t + a_3 t^2$$

where λ is the thermal conductivity in W/cm°C and t is the temperature in °C. The equation is valid between 50° and 500°C. It should be permissible, however, to extend its range by 25°C below the minimum temperature. The coefficients a_1, a_2 and a_3, as well as the standard and average deviations are given in Table 2.

Table 1 - Modal analysis of four drill core segments from the Stripa mine

Mineral	E29		E14		E13(9.0)		E13(7.5) A		E13(7.5) B	
	%	Gr. Size mm	%	Gr. Size mm	%	Gr. Size mm	%	Gr. Size mm	%	Gr. Size mm
Quartz	24.3	0.1-1.5	31.7	0.1-1.5	31.4	0.1-1.5	23.8	0.1-1.1	25.5	0.1-1.5
K-Feldspar	40.6	0.2-2.5	32.9	0.2-1.5	23.7	0.2-2.0	33.0	0.2-2.5	33.7	0.1-2.0
Plagioclase (An15)	24.0	0.2-1.5	25.4	0.2-3.0	38.6	0.2-2.5	25.3	0.1-2.0	26.4	0.1-1.5
Muscovite	5.3	0.2-2.5	1.2	0.3-3.0	1.6	0.2-3.0	1.5	0.3-3.0	3.2	0.2-2.0
Chorite-Biotite	5.7	0.1-1.5	7.6	0.1-1.0	2.5	0.2-3.0	2.6	0.1-2.0	5.0	0.1-1.0
Calcite	-	-	-	-	1.2	0.3	-	-	-	-
Epidote	-	-	-	-	0.1	0.1	0.3	0.1	0.7	0.1
Opaques (Mag., Py)	-	-	1.1	0.3	0.2	0.2	0.5	0.3	2.5	0.2
Mylonite	-	-	-	-	0.5	1.0	13.0	4.0	1.0	1.0

Table 2 - Coefficients for the least squares polynopmial and standard and average deviations

Rock Specimen	Coefficients			Deviations, %	
	$a_1 \times 10^2$	$a2 \times 10^5$	$a_3 \times 10^8$	Standard	Average
E13(7.5)C1	3.916	-5.144	3.225	1.59	1.68
E13(7.5)C2	3.614	-4.791	3.221	0.57	0.86
E13(7.5)C3	3.494	-3.966	1.896	0.73	0.77
E13(9.0)	3.396	-3.730	2.005	1.37	2.00
E14	3.601	-5.097	3.972	0.60	0.81
E29	3.671	-5.032	3.562	1.77	2.09

Figure 2 shows the thermal conductivity of specimens E13(7.5)-C1, -C2 and -C3. As one would expect, because of the mylonitic layering parallel to the axis of the specimen (and to the heat flux), the thermal conductivity of specimen C1 is appreciably higher than that of the other two specimens. At the lower temperatures this difference is of the order of 10% only and it decreases slightly with increasing temperature.

Because there is a structural difference between specimens C2 (in which chlorite filled fractures cross nearly perpendicularly the axis of the cylindrical specimen) and C3 (which has only small random cracks), there should be a difference in the thermal conductivity of these specimens. The interfaces between the chlorite filled fractures and the body of the rock should present an obstacle to heat flow. It is therefore somewhat surprising that the conductivity of specimen C2 is actually a little higher than that of specimen C3. However, the difference is rather small and it is within the limits of the accuracy of measurement.

The thermal conductivities of specimens E13(9.0), E14 and E29 are shown in Figure 3. The difference between their thermal conductivities is small. The largest difference, about 6%, occurs at room temperature. These differences, however, cannot be related to the petrographic composition of the specimens. For example, specimens E13(9.0) and E14 have a relatively high quartz content. That should make these rocks more conductive, yet it is specimen E29, which has the lowest quartz content,

that has the highest conductivity. Obviously some difficult-to-quantify factors, such as fracture distribution, degree of fracture healing and tightness of intergranular bonds, have a predominant influence on thermal transport properties of these highly stressed and fragmented rocks.

The above mentioned factors are probably the reason that the thermal conductivity of these rocks does not vary appreciably from one sample to the other [with the exception of E13(7.5)-C1], and, what is more important, that the thermal conductivity of all rocks decreases rapidly with increasing temperature.

The rapid decrease of thermal conductivity with temperature is not a desirable characteristic for rocks surrounding a nuclear repository.

For modelling thermal gradients around a repository, temperature dependence of the thermophysical properties of the rocks should be taken into consideration. In this case, if only the room temperature conductivity was used as a basis for determining the loading capacity, the steady-state temperature of the repository could be considerably higher than anticipated. As the temperature of the surrounding rocks increases, their thermal conductivity decreases causing a further temperature increase, etc.

When the thermal conductivity decreases rapidly with increasing temperature, the ratio between thermal conductivities of the hotter and the cooler layers would be smaller than in the case of rocks having low temperature dependent thermal conductivity. Consequently, for equal surface temperatures of the confining walls, the temperature gradients would be steeper for rock masses whose thermal conductivity decreases rapidly with increasing temperature. Therefore, it can be expected that the thermal gradients around a Stripa repository will be relatively steep, producing a higher concentration of thermally induced stresses over shallower depths at the surface of the repository.

Thermal gradients parallel the heat flow. Because heat will be dissipating away from the repository, the gradients will be usually perpendicular to the confining surfaces of the repository. Mylonitic shears in the Stripa granite, however, may contribute to formation of additional thermal gradients. If the orientation of these shears should happen to be perpendicular to the confining wall then, because of higher conductivity [as can be seen in Fig. 2, specimen E13(7.5)-C1], the thermal gradient in the shears would be different from that of the rest of the

rock. In consequence, a temperature gradient between the mylonitic shear and the bulk of the rock would occur. This additional temperature gradient would be perpendicular to the direction of the main heat flow and it contributes to formation of additional thermal stresses within the rock mass.

SUMMARY AND CONCLUSION

Thermal conductivities of Stripa rock specimens were measured as a function of temperature between 40° and 500°C. The difference between the thermal conductivities of these specimens was found to be small, with the exception of specimen E13 (7.5)-C1 whose thermal conductivity was on an average 10% higher. Specimen E13 (7.5)-C1 contained mylonite shears parallel to the heat flow of the measuring system. The thermal conductivity of all specimens decreases rapidly with increasing temperature, an undesirable characteristic that may cause relatively steeper thermal gradients and higher thermally induced stresses in the rocks surrounding a repository. Mylonitic shears may cause thermal gradients perpendicular to the heat flow and thus form additional thermal stresses.

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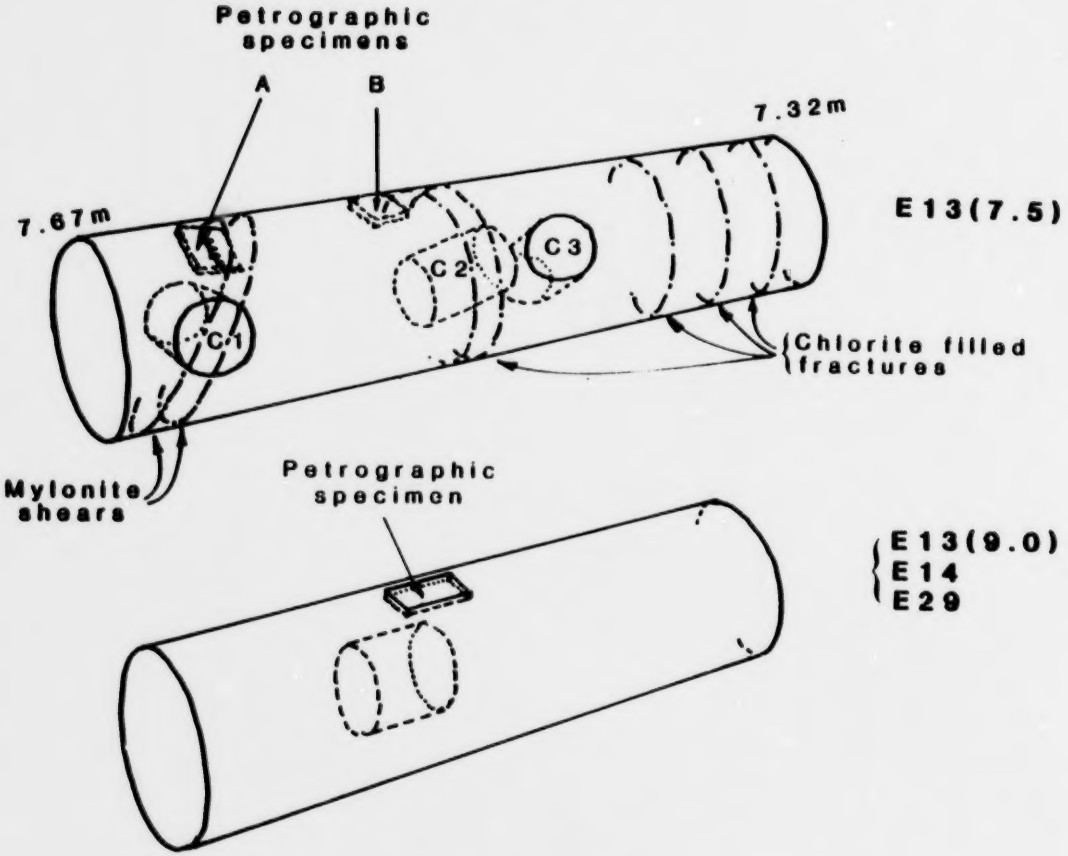

Fig. 1 - Schematic of positions and orientations of thermal conductivity specimens in Stripa drill cores. Three specimens were cut from drill core E13(7.5): specimen C1 incorporated the mylonite shears parallel to its cylindrical axis; in specimen C2 the chlorite filled fractures intersected at approximately right angles with the cylindrical axis, whereas specimen C3 contained only randomly oriented fractures. Designations 7.32 m and 7.67 m indicate the length of the core segment and its distance from the top of bore hole E13. In drill cores E13(9.0), E14 and E29, the axis of the cylindrical specimen coincided with the axis of the drill cores. Positions of petrographic specimens are indicated; petrographic specimen E13(7.5)A contained the mylonite shear.

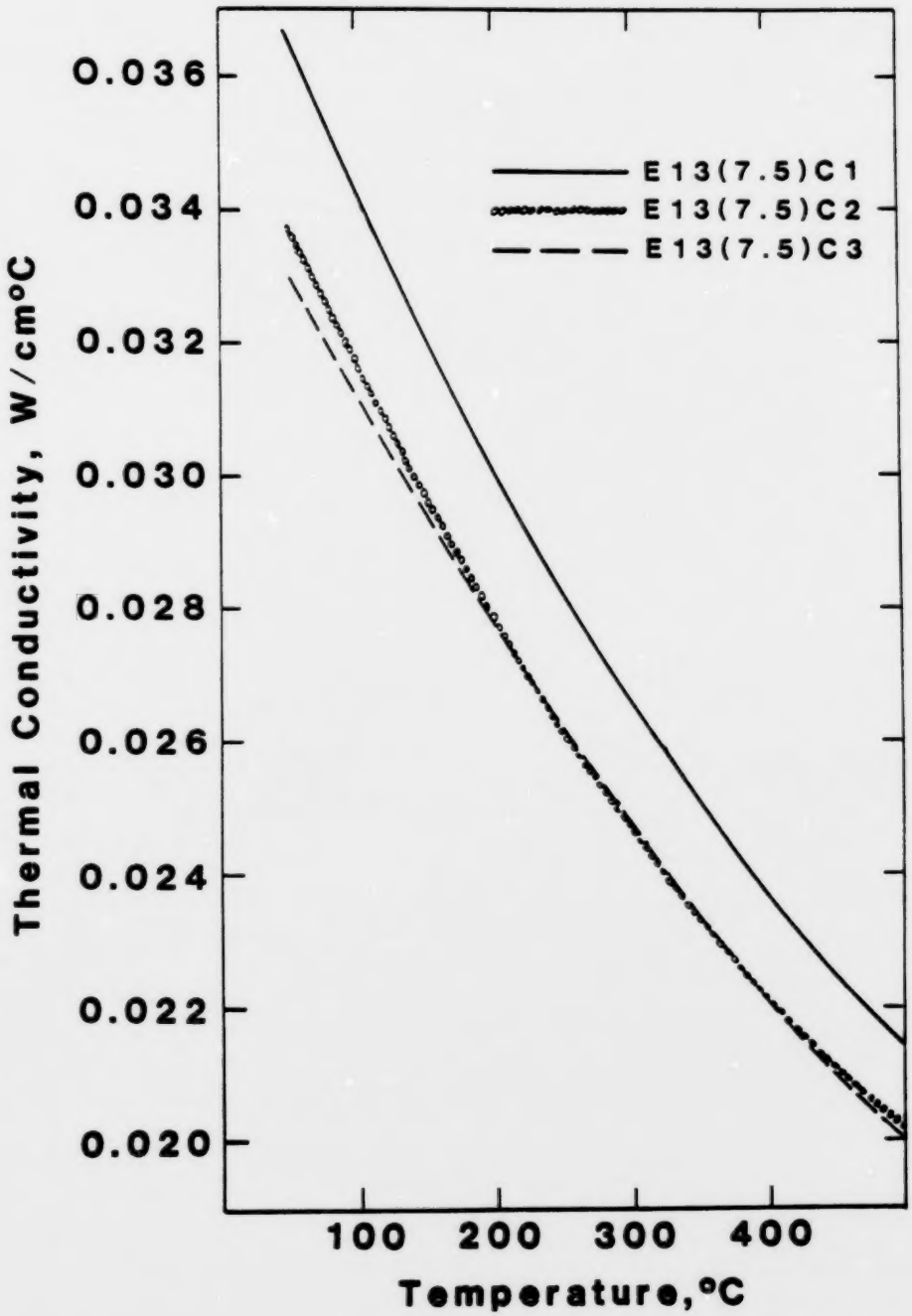

Fig. 2 - Thermal conductivities of Stripa rock specimens from drill core E13(7.5).

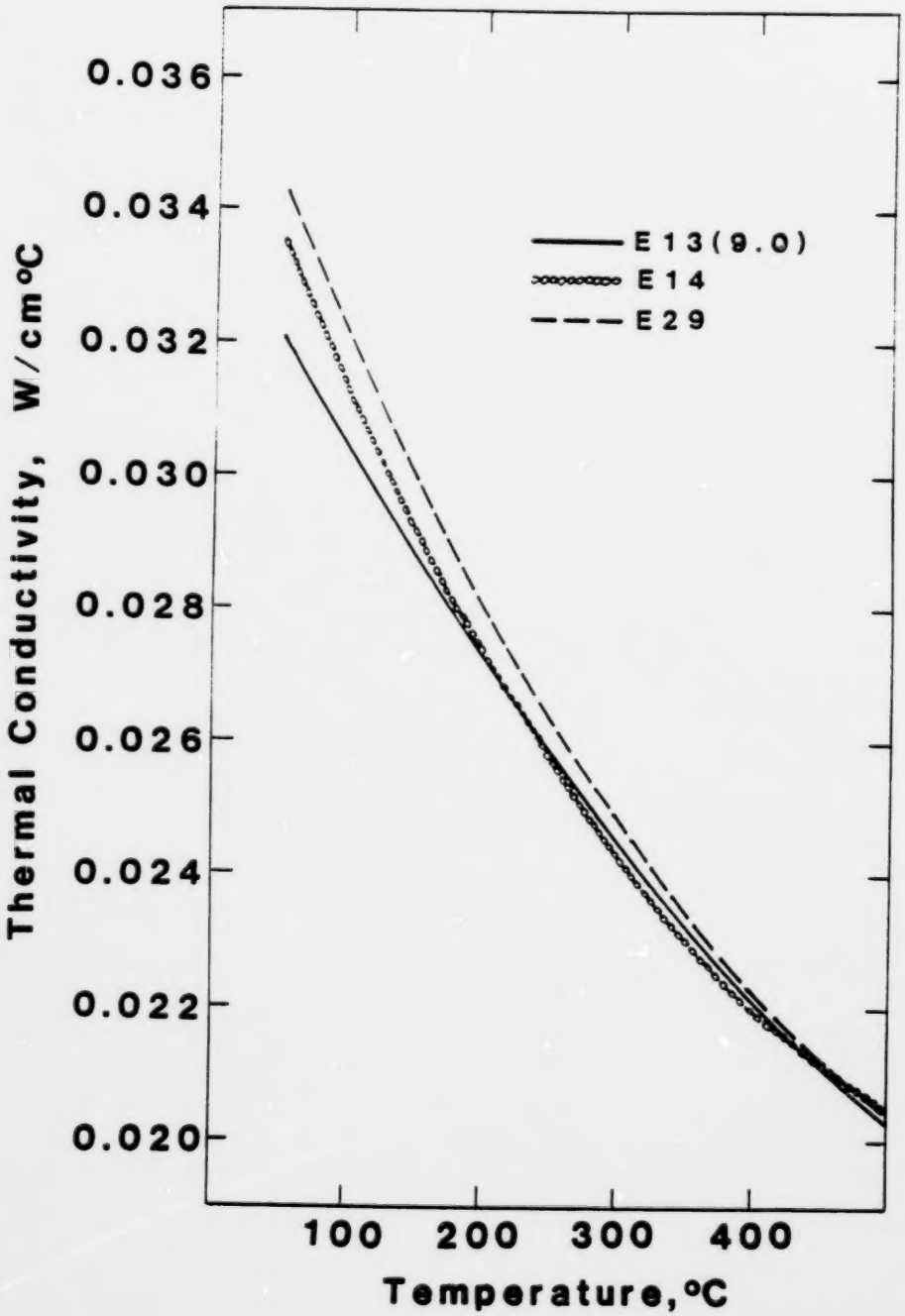

Fig. 3 - Thermal conductivities of Stripa rock specimens from drill cores E13(9.0), E14 and E29.